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DAMES & MOORE A PROFESSIONAL LIMITED PARTNERSHIP
12 COMMERCE DRIVE, CRANFORD, NEW JERSEY 07016-1101 (201) 272-8300

September 30, 1988

Ms. Janet Feldstein,
SCP - Carlstadt Project Officer,
Emergency and Remedial Response Division,
U.S. Environmental Protection Agency,
26 Federal Plaza,
New York, New York 10278

Re: Revision No. 9,
Project Operations Plan,
SCP Site Remedial Investigation,
Carlstadt, New Jersey

Dear Ms. Feldstein:

The following revisions to the March 4, 1987 Project Operations Plan (POP) address the installation of one or more groundwater monitoring wells into the bedrock aquifer.

1. **Add new Section 7.16**:

7.16 BEDROCK MONITORING WELL INSTALLATION

7.16.1 Objective

The objective of this task is to install one or more groundwater monitoring wells, open into the bedrock aquifer, to evaluate groundwater quality and flow direction in the bedrock aquifer. Boring logs from the well(s), along with chemical analysis of ground water samples and in-situ geohydrologic testing, will provide information related to the subsurface geology and aquifer characteristics in the vicinity of the monitoring well(s).

7.16.2 **Rationale**

Review of the existing literature indicates that there is no information available on the geohydrologic characteristics of the bedrock aquifer in the site vicinity. Furthermore, there is no information on the direction of ground water flow in the bedrock aquifer in the site vicinity. Therefore, a phased approach will be followed in installing the bedrock well(s), that will allow the progressive development of a site-specific data base, to guide subsequent bedrock aquifer investigations.

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The phased approach will consist of installing one bedrock well initially, and obtaining as much data as possible from the one well so that intelligent decisions can be made regarding the locations of additional wells. The bedrock will be continuously cored using an NX-size double core barrel to collect information on rock type, composition, and other pertinent geologic features. The hole will be logged using the following geophysical techniques:

- o Temperature profiling (to locate significant water-bearing zones);
- o Gamma logging and resistivity (to identify lithologic variations); and
- o Spontaneous potential (to identify formational contacts).

After the well is developed and allowed to equillibrate, a directional flow meter will be placed within the well to provide data for a preliminary evaluation of the ground water flow direction within the bedrock aquifer. A ground water sample will then be collected for analysis of all parameters previously tested for during the Remedial Investigation. One additional volatile organic analysis sample will be collected for a quick-turnaround test of volatile organic compounds (the most likely organics, if any, which may be present). A pump test will be performed in this well to evaluate the degree of hydraulic interconnection between the till aquifer and the bedrock aquifer.

Consistent with the objective of obtaining as much information as possible from the initial well, the location of this well will be adjacent to the MW-2 well cluster. This location had the highest concentrations of organics in the till aquifer of the three wells previously installed in the till (MW-2D, MW-5D and MW-7D). It is, therefore, the most probable location of the three where impacts on the bedrock aquifer, if any, will be evident.

If the initial well is at the upgradient side of the site (based on the directional flow meter results), additional bedrock well(s) may be installed at the downgradient side of the site. If the initial well is at the downgradient side of the site, additional bedrock well(s) may be installed at the upgradient side of the site. If the initial well is side-gradient at the site, additional bedrock well(s) may be installed upgradient and downgradient at the site. If the ground water velocity is not sufficient to yield a reliable ground water flow direction using the directional flow meter, two additional wells may be installed at the site in a triangular pattern with sufficient spread for evaluating the ground water flow direction; the tentative locations are adjacent to well clusters MW-5 and MW-7. The well installation procedures will be in accordance with this POP Revision.

7.16.3 Preparatory Activities

The driller will be contacted prior to the initiation of the site work to review the scope of work. The scope of work is based on our current knowledge of the site hydrogeology. All permits, licenses, approvals, certificates and authorizations required will be obtained prior to initiating any field work. An exception to this may be well permits, which may require an NJDEP waiver of owner signature.

7.16.4 Field Equipment

Field equipment to be used for this task include some or all of the following:

1. Stainless steel knife, trowel, or spatula.
2. Photoionization detector and/or organic vapor analyzer.
3. Boring and coring log sheets.
4. Decontamination detergents.
5. Deionized water.
6. Sample jars, core boxes and labels.
7. Stakes and marking flags.
8. Electric water level indicator/water level recording device.
9. Required health and safety clothing and equipment.
10. Brushes.
11. Submersible pump, with matching piping and all required plumbing supplies and tools.
12. Electrical generator.
13. Gas can, gas and oil.

7.16.5 Personnel Protective Equipment

Protective equipment and clothing required is outlined in the site Health and Safety Plan (HASP), POP Appendix B. The on-site Health and Safety Officer will be responsible for ensuring that the HASP is adhered to.

7.16.6 Procedures and Site Management

The field geologist/engineer is responsible for the proper installation of the monitoring well(s).

7.16.6.1 General Monitoring Well Installation Procedures

All monitoring wells will have state permits and will be installed by a State of New Jersey licensed well driller. The well(s) will be constructed in accordance with NJDEP monitoring well specifications, as an open hole in the bedrock, and will be double-cased in the overburden and cased in the till. If the bedrock is very fractured and there is a collapse problem, a 0.030 (minimum slot size) screen will be installed to keep the hole open. Monitoring well requirements are listed in (POP) Table 7-2. Typical monitoring well installation details are shown on (POP) Figure 7-3.

7.16.6.2 Cleaning

Prior to arriving on site, the drilling contractor will certify that the drill rig, tools and any downhole components or materials have been steam-cleaned since their last use. An on-site controlled decontamination area will be selected for steam cleaning. The lower part of the drill rig and drilling tools will be steam-cleaned at the decontamination area before initiating drilling. Steam cleaning will be done between each boring and at the conclusion of the drilling program at the on-site controlled decontamination area. Rinse water from all on-site decontamination of down-hole drilling tools will be discharged to the ground surface and diverted away from Peach Island Creek or any other surface water body. Additionally, the driller will clean the water tank and rinse it with potable water prior to drilling the first boring.

7.16.6.3 Drilling Operations

Borings through unconsolidated formations to the top of bedrock will be advanced using hollow-stem augers, wash or mud rotary techniques, whichever is most appropriate for expeditious drilling. Drilling fluids will be flushed and pumped out of the borehole before bedrock coring is initiated.

Vegetable shortening will be used to grease auger and drill rod threads, and other down-the-hole equipment as required.

If a well be installed next to an existing deep well, then no samples will be collected in the unconsolidated formations. Otherwise, the boring will be sampled continuously to the top of the till using a split barrel sampler. Sampling within the till will be performed at 5-foot intervals using a split barrel sampler. The sampling frequency may be modified, upon the discretion of the field geologist/engineer, and if conditions warrant, split barrel samples may be substituted by undisturbed samples from the same interval.

To determine the nature of the rock under the site and collect information to evaluate its geohydrologic behavior, the rock will be cored using an NX-size double-barrel coring device. To evaluate the water bearing characteristics of the rock, air will be used as a drilling fluid (unless conditions dictate otherwise). The core will be examined and logged in field to collect information on rock type and composition, attitude and density of bedding, parting, fractures, joints, cleavage, folding and faulting, dissolution and/or reprecipitation features, core length, percent recovery and RQD. The cores will be oriented using regional bedding attitude (strike 010 degrees). Fracture type and frequency information will be supplemented by observations of presence or absence of water, loss of return air, and rate of fall of drilling tools in the borehole. Coring will extend to 25 feet below the point where water was first encountered, unless the quantity of water is insignificant, in which case the boring will be continued until a yield of 5gpm is attained. The hole will then be reamed to a 6-inch nominal diameter.

During drilling operations, a PID or OVA will be utilized, to monitor the airspace directly over the borehole. These readings will be recorded on the boring log corresponding to the depth of penetration.

7.16.6.4 Monitoring Well Installation

The well(s) will be double-cased through the water table aquifer using 10-inch diameter Schedule 40 black-steel pipe set and grouted in a 14-inch hole to the top of the clay. The well casing will be constructed from 6-inch diameter Schedule 40 black-steel pipe. The well casing will be set at least five feet into competent bedrock. Rock material will be considered competent bedrock when two consecutive attempts at collecting split barrel samples (See Section 7.16.6.3) result in refusal. Rock quality will be corroborated by the first 5-foot core run.

The annular space between the well casing and the unconsolidated formations will be pressure-grouted using a cement/bentonite grout. A lockable protective steel casing will be set in a cement collar placed above the grout.

If needed, a 4-inch screen will be installed to prevent rock collapse. A sand pack and annular grout will not be needed.

All well casings will be surveyed to the nearest one-hundredth (0.01) of a foot referenced to mean sea level and located horizontally. A permanent mark will be placed on the casing as a reference point for future water level measurements. A permanent well identifier will be placed on the protective casing.

Well construction will be summarized on the boring log with a detailed sketch. Cuttings, well and drilling fluids will be disposed adjacent to the well where they came from. Precautions will be taken to avoid discharging well and drilling fluids into Peach Island Creek or any other surface water bodies.

7.16.6.6 Sampling and Logging

Overburden sampling, if required, will be performed using a split barrel sampler. A representative section of each sample retrieved will be placed in a separate jar and labeled. If a major change in soil type occurs within a sample, each soil type will be placed in a different jar and labeled. The field geologist/engineer will log each sample on the boring log. If samples are collected for chemical analysis, the procedures described in POP Section 7.8.5.6 will be followed.

A scan of the head space air quality from each field sample jar will be taken 10-15 minutes following collection with a photoionization detector and/or an organic vapor analyzer. Results of these scans will be recorded on the boring log.

After each use, the sampler will be cleaned using the following procedure (unless samples are collected for chemical analysis; see above):

1. Wash with a low phosphate detergent.
2. Tap water rinse.

To supplement the information collected by coring, the hole will also be logged using the following geophysical techniques: temperature profiling (to locate significant water-bearing zones); gamma logging and resistivity (to identify lithologic variations); spontaneous potential (to identify formational contacts).

7.16.6.7 Development and Testing of Monitoring Wells

Well Development

Each well will be developed after completion of installation using a submersible pump. Alternatively, double pipe air lifting or surge block techniques may be utilized, if the well(s) yield only small quantities of water, or if satisfactory development cannot be obtained by overpumping.

Pumping rates will be adjusted to avoid damage to the formation. The discharge rate during development should be estimated by using a 5-gallon bucket and a stop watch. Development should be continued until a sustained degree of clarity is achieved. All development water will be discharged to the ground surface and diverted away from Peach Island Creek or any other surface water body.

Well Testing

To evaluate ground water flow direction, the well will be logged using a down-the-hole ground water flow direction probe. Technical information on the methods and procedures is attached.

Following sampling (see Section 7.16.10), continuous trace water level records will be made in the bedrock and (at a minimum) the adjacent till well for a period of one month. Similarities and differences of the traces (including wave-form characteristics and event synchroneity or independence) will provide an indication for possible interconnection of the till and bedrock aquifers. In addition, the well will be pump-tested for eight hours to further evaluate the hydraulic interconnection of the till and bedrock aquifers (if any). Water levels in the pumped well as well as in the till aquifer wells will be monitored for this purpose.

Pump Test

To properly perform this test, the following equipment will be needed:

- submersible pump
- braided steel cable of sufficient length to lower and raise the pump; U-clamps for securing the cable
- sufficient length of discharge hose
- bucket or drum of known volume and stop watch
- sufficient quantity of fuel and engine lubricant
- water level indicator, watch and field book, or transducer and recorder

Measure the static water level and then lower the pump into the well. Wait until the water level returns to its initial level. Check fuel and lubricant levels in the generator or the pump, as appropriate. Turn on the pump and record the time. Immediately start recording depth to water and time of measurement. Initially, readings should be collected every 10 seconds. After the first five minutes, readings should be taken every one minute. After the first 30 minutes, readings should be taken every five minutes until the pump-down test is completed (approximately two hours). If the test is extended beyond two hours, the frequency of measurements will be reduced to every 15 to 30 minutes, depending on the duration. The pumping rate should be measured every 10 minutes and adjusted as needed, to maintain a constant pumping rate. A record of the time of the measurement and pumping rate will be made each time. When the pump-down test is completed, the depth to water will be measured and recorded. Then the pump will be turned off and the time when it was turned off will be recorded. Immediately start recording depth to water and time of measurement. Initially, readings should be collected every 10 seconds. After the first five minutes, readings should be taken every one minute. After the first 30 minutes, readings should be taken every five minutes until the water level reaches 80 percent of the initial static water level.

If a transducer and recorder will be used, then the recorder is activated at the same time as the pump is turned on. For the recovery test, the recorder will be activated as soon as the pump is turned off.

Pump test water will be discharged to the ground surface and diverted away from Peach Island Creek or any other surface water body.

7.16.6.8 Water Level Measurement Procedures

Water level measurements will be taken to the nearest 0.01 foot utilizing portable reel-type electronic water level probes. The water level is measured by lowering the electrode until the instrument sounds an audible alarm indicating the tip is in the water. The procedure is as follows:

1. Turn toggle switch to "on" and check battery by pressing test button.

2. Identify the installation (piezometer, well) designation and insert probe into desired tube.

3. Lower the probe into the tube by unreeling the tape until audible alarm sounds.

4. Record depth to water directly from the insulated tape read from the reference point on the installation.

7.16.7 **Health and Safety Guidelines**

Health and Safety Guidelines are outlined in the HASP, POP Appendix B. The on-site Health and Safety Officer will be responsible to ensure that these guidelines are followed.

7.16.8 **Field Investigation Team**

Dames & Moore and its well drilling subcontractor will perform all activities associated with the installation of the monitoring wells. The field investigation team will consist of the following individuals and/or positions:

- On-Site Coordinator
- On-Site Health & Safety Officer
- Field Geologist/Engineer
- Driller and helper(s)

7.16.9 **Schedule**

It is estimated that five weeks will be required for completion of this subtask following drilling subcontractor notification to proceed. This time includes a two-week mobilization notice to the driller, two weeks well installation time and one week geophysical logging.

7.16.10 **Ground Water Sampling**

7.16.10.1 Objective

The objective of the ground water sampling program is to collect representative water samples from the bedrock monitoring well(s). Chemical analysis of the ground water samples will provide information that will be used to evaluate ground water quality.

Ground water sample(s) from the bedrock monitoring well(s) will be collected 14 days following the installation and development of the well(s). The samples will be analyzed for the parameters listed in Table A-2 (Revision No. 4, October 26, 1987). In addition, Total Dissolved Solids, Chloride, and Sulfate will be determined. One sample will be submitted for analysis in duplicate. Daily field (rinse) and trip blanks will also be collected and submitted for analysis. Field blanks will be collected at the rate of one per matrix per day (see POP Revision No. 5 dated November 11, 1987). One trip blank will be required for each set of containers per matrix returned to the laboratory (see POP Section 6.2.2).

7.16.10.2 Preparatory Activities

The On-Site Coordinator will ensure the following:

- Sample locations have been identified:
- Necessary pre-mobilization arrangements with the laboratory have been made;
- Field equipment is operational; sample equipment is pre-cleaned; and
- Monitoring well(s) have been properly developed.

7.16.10.3 Field Equipment

Field Equipment to be used in this task may include some or all of the following:

1. Electric water level indicator
2. Plastic buckets, 1, 3, and 5-gallon
3. Photoionization detector and/or organic vapor analyzer
4. Field Sampling Records
5. Well keys and gate keys
6. Stainless steel or teflon bailers with bottom check-valve
7. Ice or freezer packs
8. Polyethylene drop cloths
9. Paper towels
10. Deionized water
11. Cleaning solvents
12. Generator
13. Gas can, gas and oil
14. Submersible pump and all necessary piping, attachments and tools
15. pH meter, conductivity meter, temperature probe or thermometer
16. Rinse bottles

7.16.10.4 Personnel Protective Equipment

Protective equipment and clothing required is outlined in the site Health and Safety Plan (HASP), POP Appendix B. The on-site Health and Safety Officer will be responsible for ensuring that the HASP is adhered to.

7.16.10.5 Air Quality Monitoring

The purpose of air quality monitoring during ground water sampling, in addition to health and safety purposes, is to detect possible airborne contaminants which may affect the sample quality as well as volatiles leaving the well.

Prior to sampling, air quality monitoring will be performed with a photoionization detector and/or an organic vapor analyzer. This will include monitoring upwind of the well, downwind, and at the well. Readings will be recorded on the Field Sampling Record (POP Figure 7-4).

7.16.10.6 Procedures and Site Management

The On-Site Coordinator is responsible for the ground water sampling task. The analytical laboratory will provide the sample containers with the shipping containers (shuttles). Containers, and any preservation chemicals added to the containers, will be in accordance with POP Appendix E. Dames & Moore will provide split samples to the EPA's designated representative upon request.

The following outlines the monitoring well sampling procedures:

1. Measure to 0.01 ft. and record the static water level in the well with an electric water level indicator. Rinse off the indicator probe with deionized water after each use to avoid cross-contamination between wells.

2. Open the sample bottle shuttle from the laboratory and inspect the bottles to make sure all the required bottles are present and labeled.

3. Attach the dedicated polyethylene suction hose (cleaned with soapy water and rinsed with deionized water) for the well to the submersible pump. Lower pump into the well so that the intake is approximately at the midpoint of the water column within the bedrock.

4. Pump out a minimum of three well volumes. Adjust the flow rate to avoid damage to the formation and, if at all possible, avoid pumping the well dry. However, if the yield of the well is too low, the wells will be purged dry and sampled within three hours of reaching equilibrium.

5. The purged water will be discharged to the ground surface, and diverted away from Peach Island Creek or any other surface water body.

6. Remove pump and suction hose from well and disconnect suction hose from the pump. Discard suction hose.

7. A dedicated pre-cleaned (see cleaning procedures below) stainless steel or teflon bailer, with its own attached dedicated length of monofilament polypropylene line, will be used for each well, and is to be stored in separate, labeled, heavy duty aluminum foil (shiny side out). The polypropylene line will be washed in soapy water and rinsed with deionized water before it is attached to the bailer.

8. Remove the bailer and line from the foil and lower it slowly down into the well by means of the dedicated length of polypropylene line. A reel may be used to hold the line, or the line maybe lowered and raised by hand with the slack portion of the line left to lie in a clean large cardboard box placed next to the well. The bailer should be lowered until it is approximately at the midpoint of the water column within the bedrock. At the completion of the sampling of a well, the bailer will be completely rinsed with deionized water and the polypropylene line discarded. For each well sampled, the bailer should be handled with a new pair of disposable plastic surgical gloves. Water samples should be carefully transferred from the bailer to the sample bottles to minimize the potential for aeration of the sample, especially those designated for volatile organics analysis (VOA). No head space in the VOA sample bottles is allowed, so special care must be taken in filling and capping these bottles. The first sample removed from a well will be that for pH, conductivity, temperature and VOA.

9. Make sure that all sample bottle caps are on snugly, but take care not to overtighten them.

10. Label the sample bottles, being sure to include: sample number and type, the name of the sample taker, the date and time, the owner, the name of the site, the well number, the depth at which the sample was taken, analysis required, sample volume, and preservatives added, if any.

11. Complete the Field Sampling Record (POP Figure 7-4).

12. Pack the sample bottles in the shuttle with ice.

13. Complete the Chain of Custody Form from the laboratory.

14. Seal the shuttle.

15. Store the shuttle in a cool location for temporary storage before transport.

16. Collect an additional sample for field tests. Perform the following field tests: pH, conductivity and temperature. Record results.

17. Lock well caps.

18. Deliver the shuttle to the laboratory within 24 hours.

Both a filtered and unfiltered metals sample will be collected from each monitoring well. The filtered sample will be field-filtered by passing an unpreserved sample once through a 0.45 um membrane filter in an apparatus that has been precleaned with a 10 percent nitric acid solution and a deionized water rinse. The apparatus will be cleaned between samples in the same manner. Samples will be discharged directly through the filtering apparatus into the container prepared by the laboratory for heavy metal samples, and then preserved immediately. The pH will be checked with pH paper.

All equipment used in collecting the sample will be cleaned prior to use or reuse by the following procedure:

1. Wash with a low phosphate detergent.
2. Tap water rinse.
*3. Rinse with 10 percent nitric acid solution.
4. Tap water rinse.
5. Methanol followed by hexane rinse (pesticide grade or better).
6. Deionized (analyte-free) water rinse.
7. Air dry.

*Note: If no metals samples are being taken, the 10 percent nitric acid may be omitted.

Only the exterior of the submersible pump will be cleaned with solvents. The inside of the pump will be cleaned by pumping a detergent solution through the pump followed by deionized water. Bailers will be pre-cleaned by the above procedure and dedicated to each well. Hoses, tubing and polypropylene line will be dedicated to each well and discarded upon completion of sampling.

7.16.10.7 Health and Safety Guidelines

Health and Safety Guidelines are outlined in the HASP, POP Appendix B. The on-site Health and Safety Officer will be responsible to ensure that these guidelines are followed.

7.16.10.8 Field Investigation Team

Dames & Moore will collect the ground water samples. The sampling team will consist of the following individuals and/or positions:

- On-Site Coordinator
- On-Site Health and Safety Officer
- Field Technician(s)

7.16.10.9 Schedule

The bedrock well(s) will be sampled no sooner than 14 days after development. The sampling effort is expected to last one day (assuming one well).

Laboratory analysis will be 6 to 8 weeks.

-oOo-

If you have any questions or comments, please feel free to contact us.

Very truly yours,

DAMES & MOORE

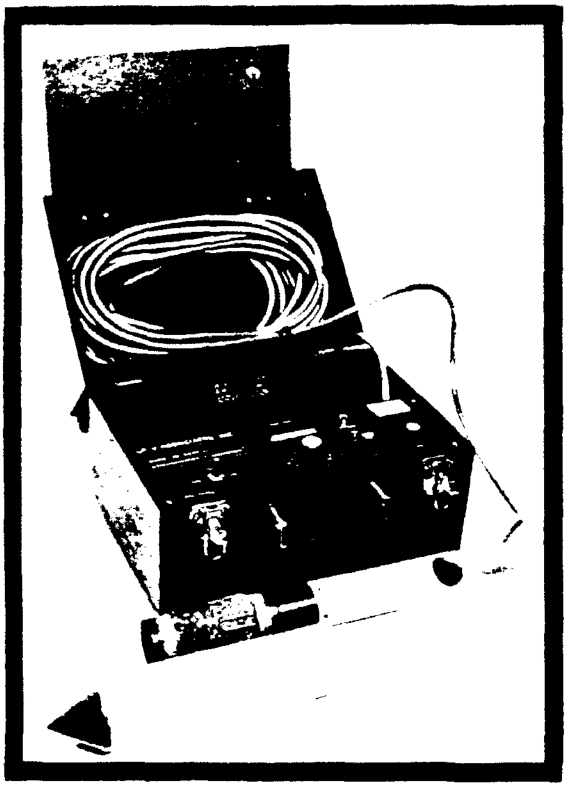
Gerard M. Coscia

Gerard M. Coscia, P.E.
Project Manager

GMC:jhm
Attachments

DIRECT MEASURING GROUNDWATER FLOW METERS TO MEET THE INCREASINGLY COMPLEX DEMANDS FOR GROUNDWATER ASSESSMENT, CONTAINMENT AND CLEAN-UP.

K-V Associates, Inc. produces instruments which measure groundwater flow direction and velocity through a range of 0.1 to 100 feet per day. In contrast to traditional labor intensive methods, the instruments display within three minutes the data necessary for the resolution of a five vector diagram accurate to ±5° in direction, ±7% in velocity.



APPLICATIONS

KVA GeoFlo® Groundwater Flow Meters* have been proven in use by major oil companies, hydrogeologists, chemical and industrial firms, consultants, spill clean-up contractors and government agencies for reconnaisance of groundwater flow to meet RCRA requirements, hazardous waste plume tracing, spill recovery projects, in-situ flow net verification for groundwater flow modeling, definition of three-dimensional zones of contribution for water supply wells, and numerous other applications where immediate determination of actual subsurface flow is useful.

PRINCIPLE OF OPERATION

Ten radially arrayed thermistors surrounding a central heat source extend from the sensor probe. These elements are contained in a flexible screened end cap bag filled with sand or other appropriate media. The probe is placed directly in saturated soils or suspended in a uniformly screened well by interlocking rods and oriented by a small compass. As the measurement sequence is initiated, a heat pulse is created at the central source. Upon signal from the timer (1½-3 minutes depending on the model), the operator records the displayed values for five vectors. These values represent the temperature bias across opposite thermistors resulting from entrainment of the heated water mass in the movement of groundwater through the porous soil matrix.

The values displayed are pre-determined by the operator by calibration, using the Darcimeter™ Flow Chamber supplied and may represent linear or volumetric flow. The resultant vector representing flow direction and velocity is then calculated using a work sheet or a computer program supplied for TI-58C/59 or HP-41C calculators.

Use of a Geo Flowmeter for the Determination of Ground Water Flow Direction

by Marilyn Guthrie

Abstract

The Geo Flowmeter is manufactured by K.V. Associates of Falmouth, Massachusetts, and is used to determine ground water flow direction and velocity in monitoring wells or open boreholes. It operates by emitting heat pulses and measuring subsequent temperature increases carried by the ground water movement. The meter can be used in wells as small as 2 inches in diameter and only a single well is required for determination of ground water flow direction and rate.

This paper is a case history of the use of the Geo Flowmeter in a complex hydrogeologic setting consisting of a partially above grade landfill located between a navigable waterway and a large storm water impoundment basin. Mounding effects of the landfill, tidal changes in the channel, varying water levels in the impoundment basin and a complex substrate (alternating layers of sand, silt and clay) presented a challenge for ground water interpretation and analysis. The Geo Flowmeter was lowered into existing monitoring wells surrounding the landfill to determine ground water flow direction and rate. Sensitivity of the meter was sufficient to distinguish two separate flow directions in a single well screen. Later investigation involving installation of piezometers, long-term ground water level monitoring and plotting of ground water contours verified initial findings of the meter.

This article presents numerous graphs and pictures to illustrate field use of the instrument and discusses advantages and disadvantages of its use. Actual field data collected is included to provide a basis for evaluating the accuracy of the instrument and identifying situations where it may be used.

Introduction

The Geo Flowmeter, manufactured by K.V. Associates of Falmouth, Massachusetts, is a portable field instrument used for determining ground water direction and velocity. It can be used in saturated soil, open boreholes and in different size wells.

The instrument operates by emitting heat pulses and simultaneously measuring the temperature differential around the circumference of the well. The heat pulses are carried in one direction by the movement of soil pore water, thus causing a temperature differential. By plotting the measured temperature differential in vector form, the direction of ground water flow is determined.

K.V. Associates has used this instrument for measuring ground water direction and velocity in many different settings. In one reported case, borings were made through rock and screened in the sandy till below and the meter was used to predict the deep and shallow flow movement. Studies have also been done to determine flow through lakes and ponds.

This paper documents use of the instrument in the understanding of flow in a complex hydrology setting. Operating principles, operating instructions and supporting data documenting its accuracy are also presented. Finally, advantages and disadvantages of using the instrument are presented based on actual field experience.

Methods and Materials

Figure 2.1 shows all the components of the K.V. Associates Geo Flowmeter. The instrument operates on the theory of heat movement by the soil pore water as illustrated by Figure 2.2.

The instrument consists of a heat source sur-

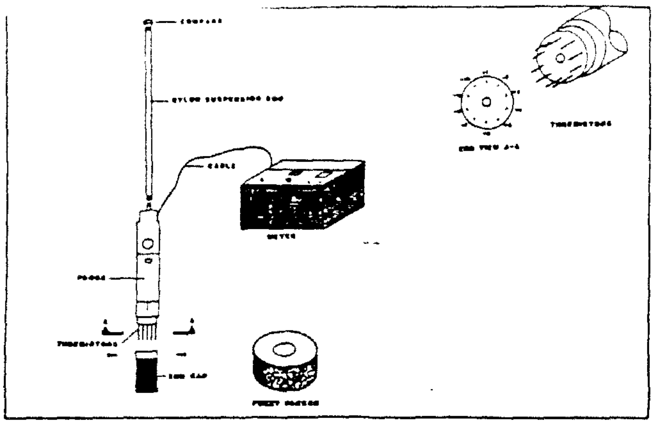


Figure 2.1 Instrument setup for Geo Flowmeter

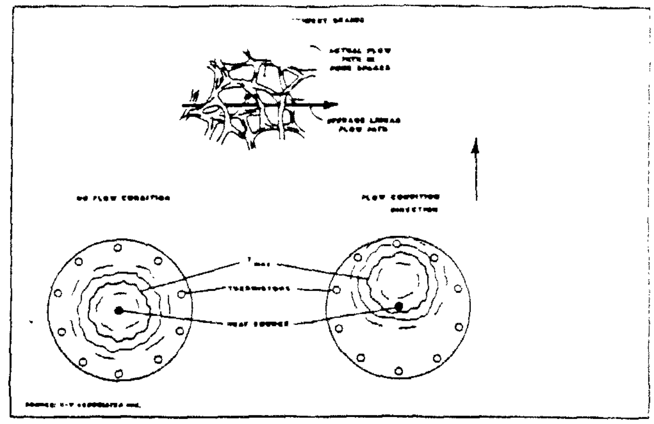


Figure 2.2 Concept of flow through pore spaces in soil and Geo Flowmeter flow conditions

rounded by 10 thermistors, each of which are paired to another making a total of five pair (Figure 2.1). The relative thermal difference is displayed, and the sign (+ or -) of the value indicates which of the two thermistors is reading the higher temperature. For example, if thermistor +1 is hotter than its pair, thermistor -6, the display will be a positive value indicating flow (heat) in the direction of +1 (Figure 2.2).

In a no-flow condition all thermistors see the same temperature rise with time and there is no net difference between pairs (Figure 2.2).

Equipment Description

Figure 2.3 illustrates how the probe is set up for down the well use. In short, the end cap which contains glass beads is attached to the probe and the probe is then suspended in the well by nylon rods. The compass tee is then attached to the last rod for orientation purposes.

The diameter of the well will determine the type of attachment that must be placed on the end of the probe. The first type of attachment, useful only in 2-inch wells, is called an end cap and consists of a grey netting filled with glass beads (Figure 2.1). This end cap is attached directly to the probe with two small screws and surrounds the probe with a loose porous medium (the glass beads). The second type of attachment is called a fuzzy packer and can be used in 2-, 4-and 6-inch wells. The fuzzy packer is a cylinder with a fuzzy covering made to fit tightly down a well (Figure 2.1). This cylinder is also filled with small glass beads to provide a porous medium through which the flow will stabilize (Figure 2.1). The fuzzy packer also attaches with two mounting screws directly to the probe.

The probe is suspended in the well by the 5-foot nylon suspension rods which join together by snap buttons (Figure 2.3). The probe is then lowered down the well until it is at the depth of the screen. Care must be taken to be sure that the probe is set in the screen of the well and not just in the water. (It is necessary to know the depth of the screen before heading to the field.) Using a pipe ring to hold the nylon tubing, the probe can be suspended at a certain depth.

Once the probe is set at the proper depth, it must be oriented to north. To facilitate this, the compass is placed on the top most attached nylon rod and snapped in (Figure 2.1). The snap attachment ensures that the number +1 probe is lined up with the north reading on the compass. When the compass arrow is oriented toward the north, the probe is ready for use.

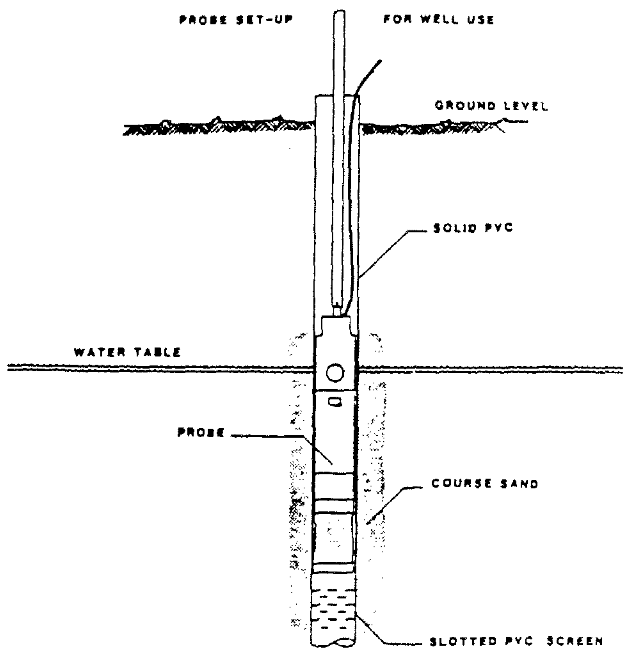


Figure 2.3 Downwell setup for the Geo Flowmeter

Operating Procedure

The rotary switch selects which pair of thermistors are being read and displayed. (Figure 2.4, #5.) The flow rate and direction indicator by + or - is displayed on the LCD (liquid crystal display) as the rotary switch is moved from channel to channel.

Readings for each channel should be monitored at short intervals until a stable display is observed. Values should be within +10, however, they may be larger with a greater sensitivity setting. Values for the five channels are recorded on a Ground Water Flow Worksheet in Column A, as illustrated in Figure 2.5. After pressing the START button, the LED will flash to indicate that a measurement cycle is in progress. When the beeper sounds (1½ minutes for Model 30), values from respective channels in the "end" column B are immediately recorded. The RESET button can be pressed to silence the beeper.

Next, the probe must be oriented in the south direction again allowing at least five minutes for heat to dissipate and flow to re-establish. It is suggested that the fuzzy packer be raised and lowered several times in order to help the heat dissipate. After five

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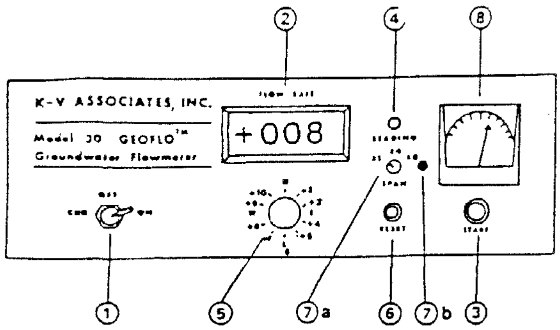

OPERATING CONTROLS

Item	Function	Instruction
1	Switch applies batteries to instrument operation or external battery charger.	Push toggle to right to power instrument. Push left to charge battery.
2	Panel meter gives digital flow rate.	Values are typically read in units of ft/day.
3	Switch starts measurement cycle and heat pulse.	Push to start when probe is in place.
4	LED flashes during reading time of measurement cycle.	Do not disturb probe during measurement cycle.
5	Rotary switch selects direction, i.e. one of 3 pairs of opposed thermistors in probe; thermistor #1 oriented North.	Record readings for each position before and after measurement cycle.
6	Push button reset timers.	Push to reset buzzer or interrupt a measurement cycle in process.
7	a) Span switch adjusts sensitivity.	a) 1X= low; 4X= medium; 8X= high sensitivity.
	b) Adjacent multi-turn span pot makes fine adjustments to span switch levels.	b) Adjustments clockwise increase sensitivity.
8	Ammeter displays current flow.	Provides confirmation of current flow and indicates battery condition.

1-3

SOURCE: K-V ASSOCIATES INC.

Figure 2.4 Operating controls for the KV Associates Geo Flowmeter

minutes the cycle can be repeated and readings recorded in the second set of columns. Column B is then subtracted from Column A and the results placed in Column N (or C) as shown in Figure 2.5; repeating the procedure in Column S. Then Column S is subtracted from Column N and divided by 2 (the result is recorded in Column F). Each reading in Column F is then divided by the largest absolute value in this column. Vectors can then be drawn on the circular diagram on the right side of the worksheet for each value with the largest value being 1. Then starting at the end of the largest vector, draw vectors head to tail, keeping their respective lengths and directions the same. After redrawing the four other vectors, a line drawn from the center through the head of the last vector will intersect the outermost circle of the paper at a degree reading representing the principal direction of flow.

This instrument was also used in open core borings. In this case the prongs of the probe are inserted directly into the soil and readings taken as before. If the bottom of the hold consists of clay, placement of the probe may be difficult since the nylon rods bend easily. When the probe is rotated to the south, it is suggested that the probe be pulled completely from the hole and sediment removed from between the prongs of the probe.

Velocity of the ground water movement can also be computed as follows:

$N_c \times F_L$ = feet/day through (V_G) glass beads

Where:

N_c = Calibration number

F_L = Largest value in the Column F (worksheet)

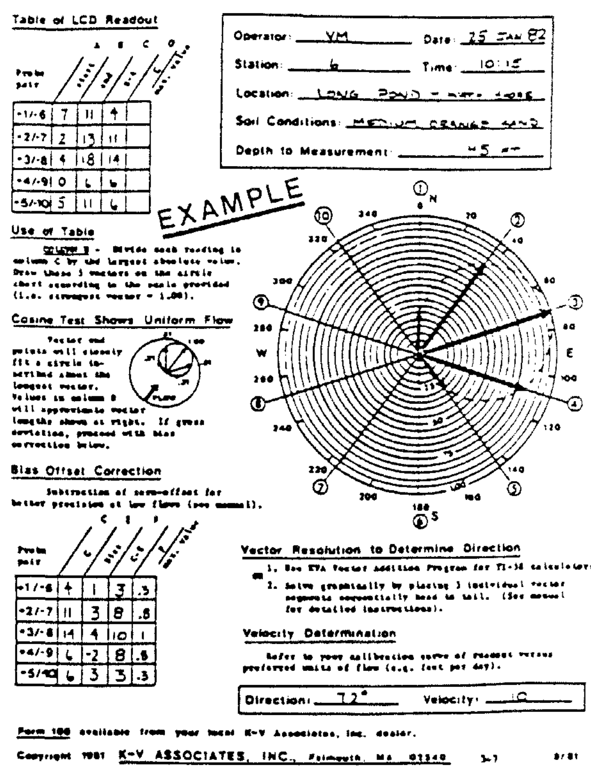

Figure 2.5 Ground water flow worksheet

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Then, using the ratio:

$$\frac{.33}{V_G} = \frac{P_s}{V_S}$$

Where:

.33 = the void space of the glass beads

V_G = feet/day through glass beads

V_S = feet/day through the soil

P_S = porosity of soil calculated by filling a graduated cylinder with 25 ml of water and then dumping soil into the water until the soil height reaches 25 ml. Then dividing the difference by the old measurement (25 ml) to compute void space.

Case History

Figure 3.1 shows a specific site layout where the KV-Meter was used for investigative purposes. The site under investigation is an above grade landfill, approximately two (2) acres in size. It is located adjacent to an intercoastal waterway. Ground water in this area is affected by tidal changes and the water level in a storm water impoundment. The geology of the area is made up of relatively complex river deposits of alternating layers of sand, silt and clay (Figure 3.2)

Concern over the area began with the installation of Well-A (Figure 3.1) Initial and later tests showed low pHs in this well and the source of the low pH was unknown. No record of what was deposited in the landfill was available and many pipelines run through this area making source determination difficult. A second well, Well-B, was placed near the storm water impoundment (Figure 3.1) but showed a relatively normal ph of 6 units.

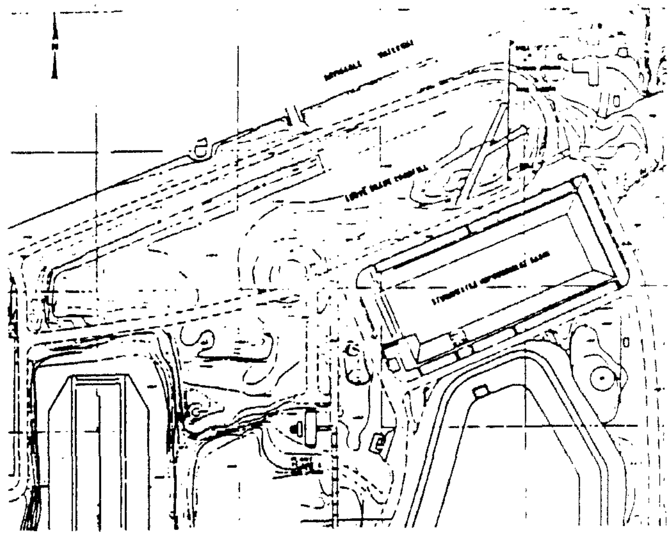

Figure 3.1 Geo Flowmeter site map

The Geo Flowmeter was inserted in these two wells and the resultant readings are shown on Figure 3.3. The shallow reading (13 feet) in Well-A and the deep reading (25 feet) showed ground water flow to be in the direction of the water way. However, the shallow reading in Well-B showed flow to be in the direction of the storm water impoundment basin.

A series of new wells (Figure 3.4) were installed in order to determine the presence of contamination. From the new wells and the reading from the Geo Flowmeter, flow lines were drawn on a cross section to show the shallow and deep flow directions as shown in Figure 3.5; the above grade landfill is causing a slight

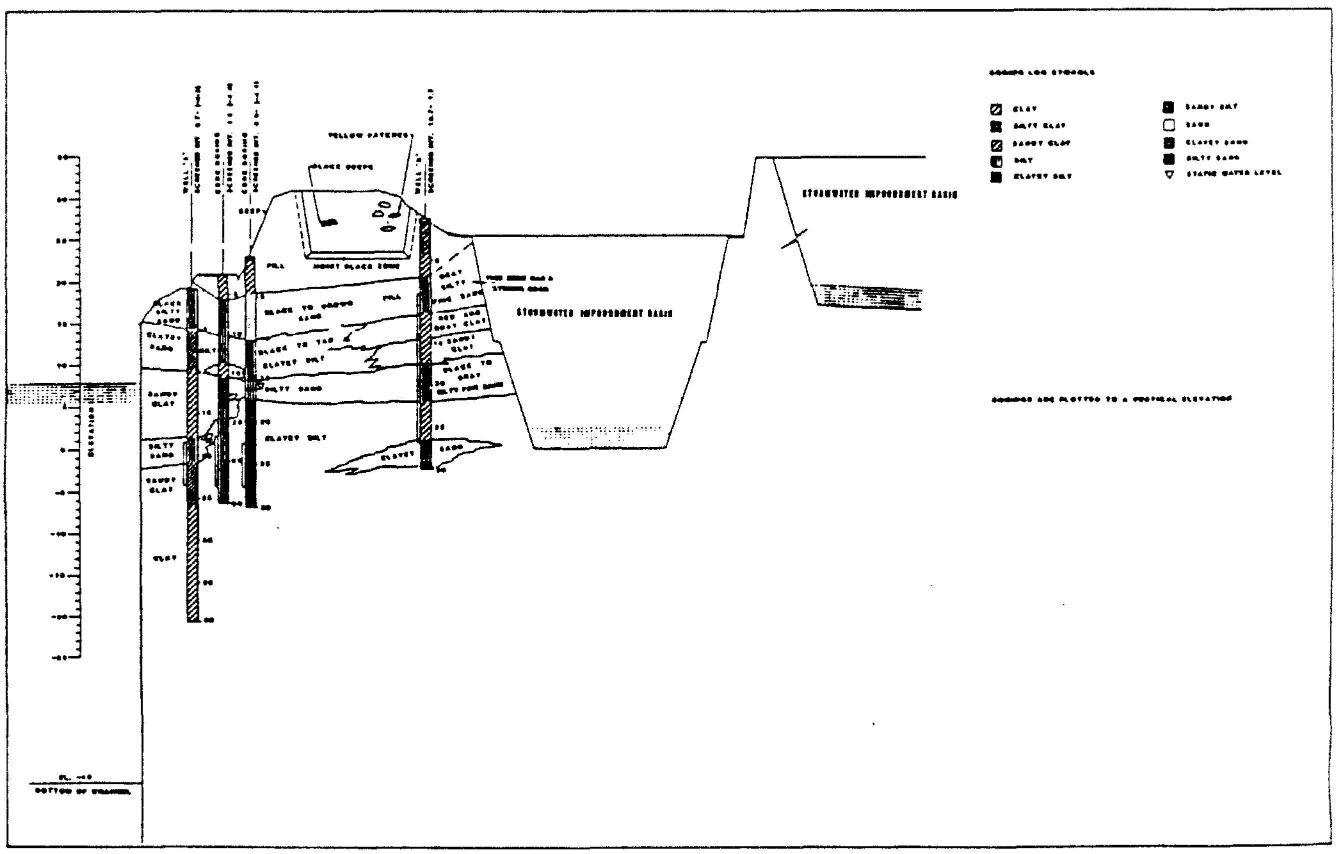

Figure 3.2 Subsurface cross section of above grade landfill

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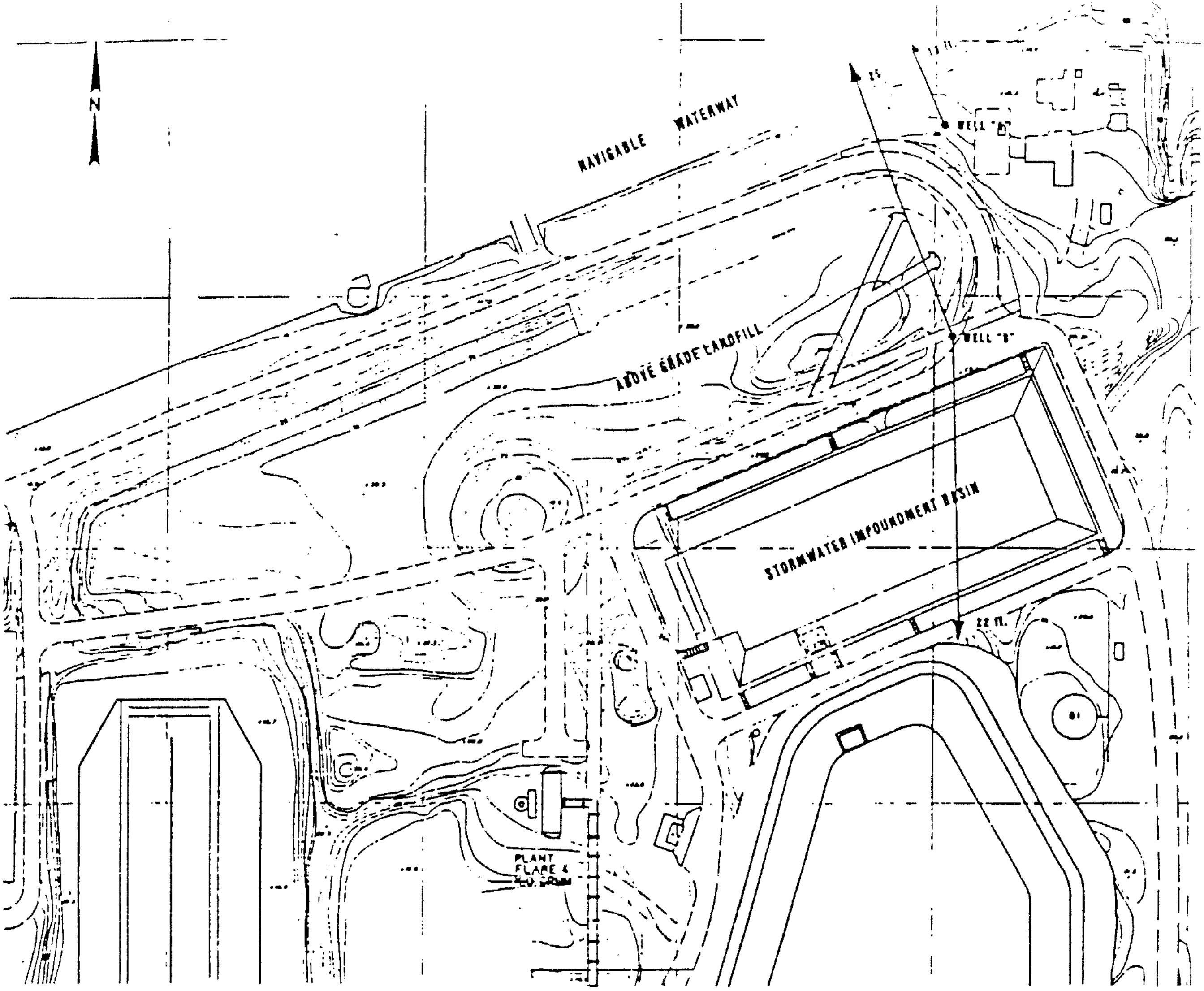

Figure 3.3 Site map with Geo Flowmeter readings

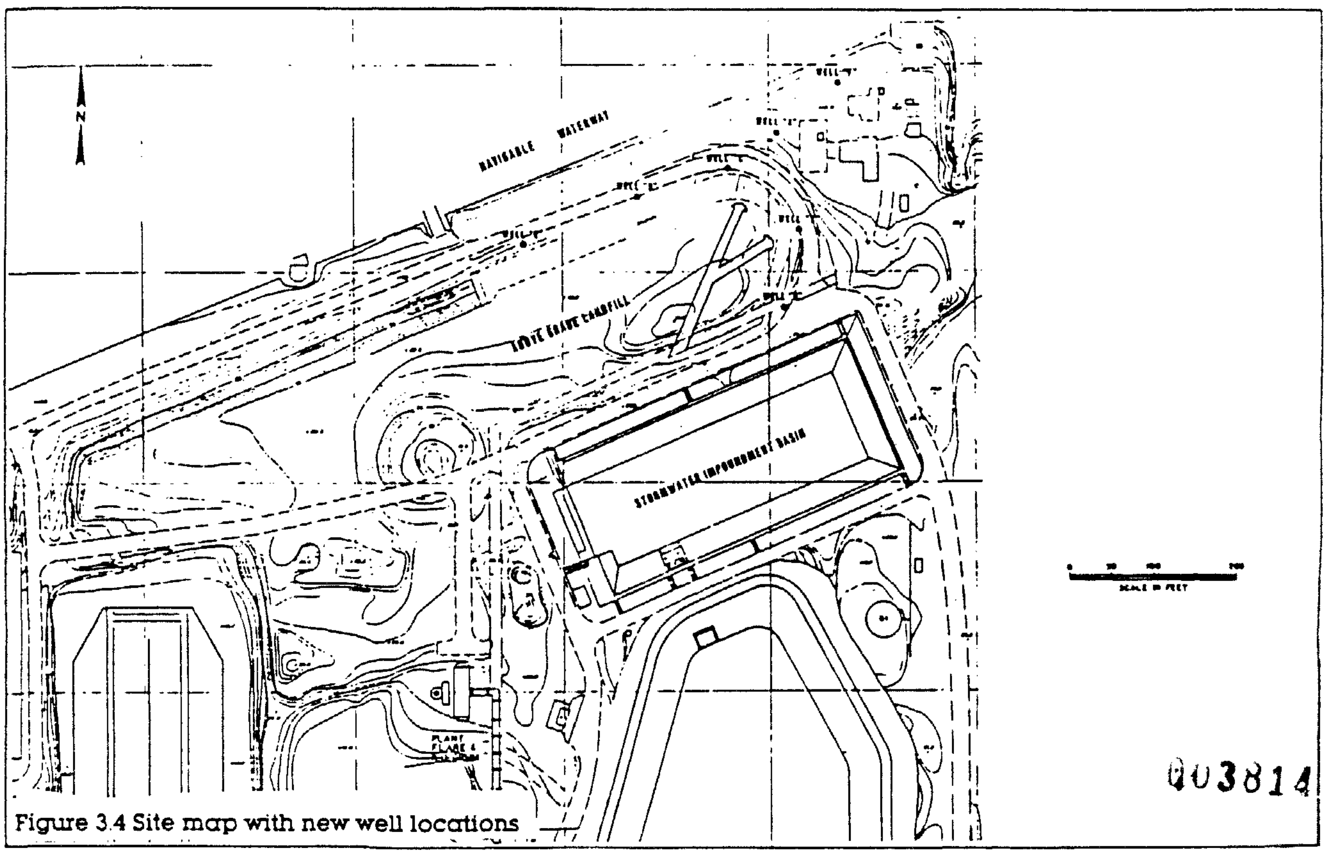

Figure 3.4 Site map with new well locations

mounding effect. Further, the storm ·ter basin is continually pumped dry causing the lc gradient to be toward the basin. However, the underlying regional gradient is toward the waterway.

Additional evidence to support the effects of the storm water basin was gathered from continual water level monitors placed in the basin, Well-A, Well-B and the water way. As rainfall was collected and the water level of the basin increased, Well-B adjusted accordingly. On the other hand, Well-A was affected directly by the rising and falling of the waterway.

Conclusions

The Geo Flowmeter is very appealing because it is portable and easy to use once operation of the instrument is mastered. It is sensitive enough to give readings of two different directions in a single screen and its sensitivity to local ground water flows makes it very attractive. Regional ground water flows derived from wells may miss local situations which may be important in analysis of underground storage facility settings. When compared to an extensive drilling program, it is relatively inexpensive. In addition, much information can be derived by using the instrument and only a few wells.

Disadvantages would include the time and effort it takes to understand and use the instrument properly. The operating manual certainly needs to be more explicit. It must also be remembered that in many cases the meter will indicate a very local situation that could be subject to change. For example, the flow in some wells actually reversed because of tidal situations. Not all readings taken during the testing of this instrument were 100 percent convincing, particularly those taken in open boreholes. In a deep boring, it was very difficult to determine if the instrument was placed in the soil correctly.

Acknowledgments

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Biographical Sketch

Marilyn Guthrie is employed by the ARCO Petroleum Products Co. and is involved in geologic investigations, ground water monitoring, hydrocarbon recovery and RCRA permitting at the Houston Refinery in Houston, Texas. This article was written as a result of the author's experience with the Geo Flowmeter at the refinery.

Guthrie is a graduate of Baylor University with a bachelor of science in geology. Upper level classwork was completed in hydrogeology and hydrology; undergraduate thesis dealt with the surface water problems of a dam in Waco, Texas. Graduate work is currently being completed at the University of Houston.

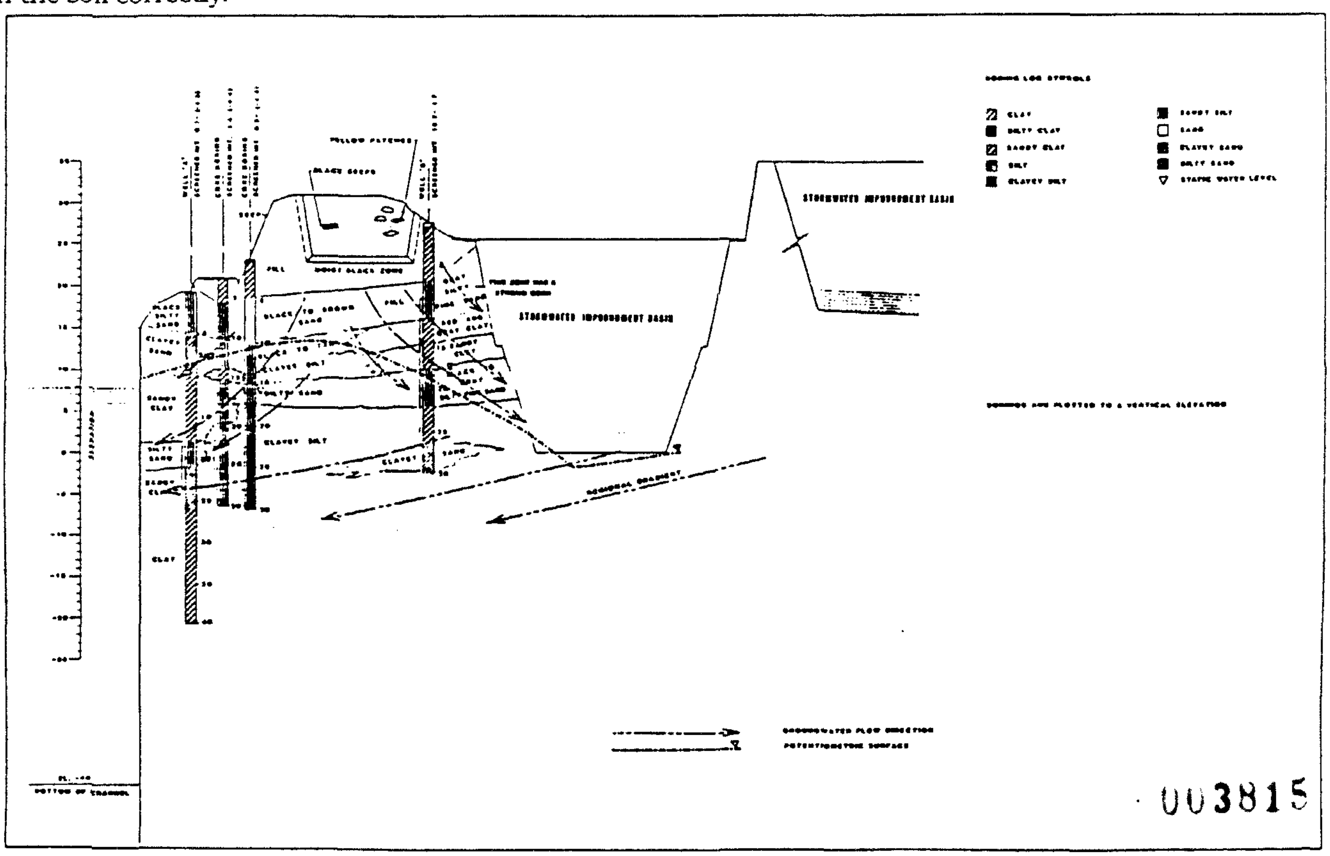

Figure 3.5 Subsurface cross section with flow lines of above grade landfill